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Spatial and seasonal variation in surface water quality of Nan river, Thailand

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Abstract

The quality of Nan river which is an important surface water resource in Thailand was evaluated by using physico-chemical and biological parameters and together with the water quality index (WQI). The aim of this study was to understand the variation of water quality in accordance with locations (i.e. midstream and downstream) and seasons (i.e. wet and dry seasons) from 2012 to 2016, which is beneficial for water resource planning and management in the Lower Northern Thailand. The data of all 15 water parameters were collected from Pollution Control Department (PCD), Thailand. The data revealed that some parameters including turbidity, total solids (TS) and suspended solids (SS) were significantly affected from locations and seasons ($\rho < 0.05$); the larger values were observed in the downstream and wet season rather than the midstream and dry season. In the meanwhile, the nitrate (NO_3^-) and total phosphorus (TP) concentrations was significantly affected from only locations; the higher concentrations were found in the downstream rather than the midstream. The average WQI values were 67.9 and 68.7 in wet and dry seasons respectively, which classified as a moderate quality. There was no spatial and seasonal variation in Nan river quality. In addition, the majority of sampling water (of 70%) was in Class 3 in accordance with the Thailand surface water quality standard. The results presented that the increasing agricultural and residential areas along the river did not affected on decreasing the water quality. The self-purification of Nan river was still effective, however the regular monitoring is still necessary for interpretation of water quality and management measures.

Keywords: Nan river, surface water quality, water quality index, water pollution

1. INTRODUCTION

Nan river is one of the most important rivers in Thailand, and the river is consumed for several proposes including agriculture and domestic uses. According to land use categories by Land Development Department of Thailand [1], the land use priority in Nan river basin is agriculture for paddy fields and upland field crops; the area was 18,170 km^2 in 2009, 18,416 km^2 in 2013, and 14,389 km^2 in 2016. The average total agricultural area was around 41-53% of Nan river basin during 2009-2016 [1]. Due to a recent intensive farming and industrial agriculture, a large volume of nitrogen fertilizer has been used to increase agricultural products [2]. The excess amount of fertilizer causes health and environmental problems. For example, nitrate (NO_3^-) which is a pollutant from nitrogen fertilizer consumption was contaminated in groundwater wells and streams around the asparagus farms in Kanchanaburi; the concentration was over 150 mg/L [2]. In Thailand, the groundwater wells and streams are common resources for drinking water. The above contaminated value was exceeding the safety limit, which is suggested by World Health Organization [3].

Similarly, the population in Nan river basin has been increasing from the recent urbanization extension; the population was 3.416 million in 2012, and increased to 3.418 million in 2014 and 3.420 million in 2015 [4]. Due to a daily consumption, around 282 L of wastewater was generated by a person in 2012, and the wastewater volume increased to 316 L in 2017 [5]. This represented the large volume of domestic wastewater was discharged to the river and environment. According to Luanmanee et al. [6], a domestic wastewater (i.e. combined toilet and cafeteria wastewater) in Bangkok was characterized; high organic carbon content (measured in biochemical oxygen demand; BOD) of 88 mg/L and total nitrogen (TN) of 43 mg/L were observed, even though the wastewater was pre-treated by screen and settlement tanks. For the standard of surface water in Thailand [7], the organic carbon and nitrogen contents should not exceed the limits of 1.5 mg/L for BOD, 5 mg/L for nitrate (NO_3^-) and 0.5 mg/L for ammonia (NH_3), when the water is classified in Class 2 using for daily consumption, aquatic organism conservation, fisheries and recreation. Therefore, the continuous increase in agricultural area and population from 2012 to 2016 can negatively affect the quality of Nan river.

Not only the agriculture and domestic purposes, Nan river is also used as a natural resource for producing the water supply (tap water) by Provincial Waterworks Authority. The natural water is passed through traditional treatment processes including coagulation, flocculation, sedimentation, filtration and chlorine disinfection, and then distributed via water supply network to households [8]. When the quality of Nan river becomes worse rather than the prior status, the water supply is significantly affected. This is because the designed treatment processes cannot efficiently remove the high concentrations of pollutants.

Presently, the quality of Nan river is regularly monitored by various government organizations including Pollution Control Department (4 times/year) [9], Royal Irrigation Department (12 times/year) [10], Provincial Waterworks Authority (12 times/year) [11], and Environmental Office Region (4 times/year) [12]. The overall status of surface water in Thailand is classified into Class 1-5 by using water quality indicators such as BOD, dissolved oxygen (DO) and total coliform bacteria (TCB); Class 1 refers to very good quality, Class 2 refers to good quality, Class 3 refers to moderate quality, Class 4 refers to poor quality and Class 5 refers to very poor quality [7]. In 2000, Nan river was in Class 2; BOD 1.5 mg/L, DO 6.7 mg/L and TCB 215 MPN/100 mL [13]. In 2001-2003, the river was in Class 4 [14] and the river was recovered to be in Class 3 in 2004 – 2012 [15]; BOD 1.9 mg/L, DO 6.6 mg/L and TCB 3,470 MPN/100 mL in 2006. Further, the spatial variation in water quality has been reported in previous studies [16-18], due to the pollution hotspots such as industries, paddy fields and households along the river [18-20]. This effected on decreasing downstream water quality. The season is also a factor effecting on the water quality; the water quality of Yellow river flowing through Lanzhou city (China) was better during the dry season than the wet season [21]. Further, the high level of precipitation in wet season increased the total organic carbon concentration and diluted the fluoride concentration from the dry season in Maji ya Chai River in Northern Tanzania [22].

This is due to Nan river is divided into upstream, midstream and downstream with different land use priority; the upstream is forest, midstream is agriculture and downstream is community. Therefore, the water quality of midstream and downstream is possibly affected from the urbanization extension. In the meantime, a large difference in precipitation between the wet season (~1161 mm in 2012-2016 [23]) and dry season (~158 mm in 2012-2016 [23]) is also affected on the surface water quality of Nan river. Therefore, the aim of this study was to evaluate the water quality of Nan river from 2012 to 2016 by using statistical analysis and water quality index (WQI). The influence of locations and seasons on the water quality was also discussed. The realization in water quality variation can benefit the local people and government on pollution prevention and water resource management.

2. MATERIALS AND METHODS

2.1 Study area

Nan river is one of four main rivers; Ping, Wang, Yom and Nan in the northern part of Thailand. The river originates from Luang Prabang mountain in Nan Province and runs in the north-south direction through Nan, Uttaradit, Phitsanulok, Phichit and Nakhonsawan Provinces (see in Figure 1). The total distance is around 770 kilometers [19]; ~0-250 kilometers is defined as upstream, ~251-500 kilometers is classified as midstream, and ~501-770 kilometer is for downstream. Nan river joins the other main three rivers at Nakhonsawan Province and becomes the origin of Chao Phraya river which is the important river in the central region of Thailand.

In this study, the water quality of Nan river was assessed in the midstream and downstream, where are the sensitive areas for pollution contamination. Two sampling locations of ST01 and ST02 in Uttaradit Province were represented the midstream, and the other two sampling locations of ST03 and ST04 in Phitsanulok and Phichit Provinces were represented the downstream. The sampling locations and details are summarized in Table 1. The sampling seasons were divided into wet season (May – October) and dry season (November – April) [24], and there were two sampling times in a season.

2.2 Data source

The values of physico-chemical and biological parameters including temperature, pH, conductivity, total dissolved solids (TDS), turbidity, hardness, total solids (TS), suspended solids (SS), NO_3^-, total phosphorus (TP), DO, BOD, NH_3, total coliform bacteria (TCB) and faecal coliform bacteria (FCB) at various sampling locations and seasons during 2012-2016 were collected from Pollution Control Department (PCD), Thailand. The spatial and seasonal variation in the water parameters and water quality was analyzed using statistical test; analysis of variance (ANOVA) at a significance level of 0.05 ($\rho < 0.05$).

2.3 Calculation of water quality index

The water quality index (WQI) was developed for statewide assessment of surface water. There are five water parameters are included in WQI model; DO, BOD, NH_3, TCB and FCB. The calculation and evaluation of WQI model [25] are summarized in Tables 2 and Equation 1.

Total score = Average score of 5 parameters – Extra score (1)

Later, the water quality of Nan river at various locations and seasons is classified in accordance with the total score of WQI (see in Table 3). The extra score in Equation 1 is evaluated by comparing the lowest score to the average score, and following the below criteria [25];

- No difference: the extra score is 0.
- One level difference: the extra score is 10.
- Two levels difference: the extra score is 15.
- Three levels difference: the extra score is 20

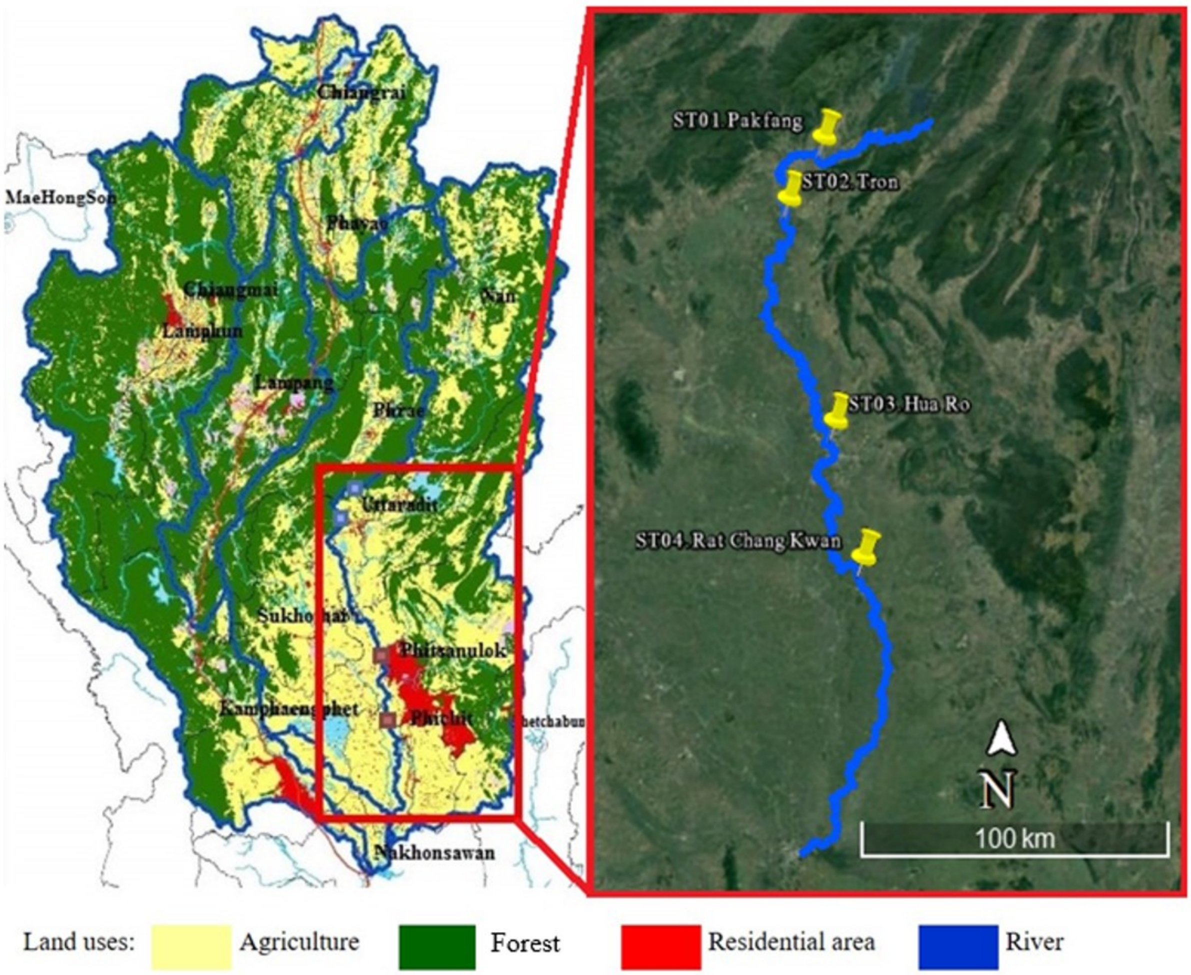

Figure 1 Land use and monitoring station, Nan river.

3. RESULTS AND DISSCUSION

3.1 Physico-chemical parameters

During the five years from 2012 to 2016, the quality of Nan river was basically evaluated by the water parameters of temperature, pH, hardness, conductivity, TDS, turbidity, TS, SS, NO_3^- and TP. The average and range of these water parameters at various locations and seasons are illustrated in Figures 2(i) – 2(x) and Table 4. The water temperature is a seasonal parameter and related to ambient temperature [26]. The minimal temperature of Nan river was 25.8 °C in the dry season and the maximum was 34.7 °C in the wet season. The average temperature was 29.5 °C for different locations and seasons. A wide range of pH was obtained in the midstream and wet season, however the average pH of Nan river was the similar value of around 7.7. This is because the relative low pH of 5.8 rather than the average pH was detected in one sampling water at ST01 in the wet season. The highest hardness concentration of 130 mg/L was also found at the same sampling water at ST01 and wet season, however the value was not exceeding the standard limit for water supply of 300 mg/L [27]. The conductivity was varies from 120 µS/cm to 200 µS/cm in all locations and seasons. Since the conductivity measures the capacity of water to conduct electrical current, it is directly related to the concentration of salts dissolved [28], and therefore to the TDS concentration which ranged 40-180 mg/L in this study. A wide range of turbidity concentration was observed in different locations and seasons. The high turbidity of Nan river was detected in the downstream and wet season. Although the turbidity and solids parameters are not included in the surface water standard [7], they are importantly indicating parameters for water quality; the turbidity limitation of qualified water supply is 4 NTU [27]. Similarly, the other solids parameters including TS and SS reached the maximum of 350 and 204 mg/L in either downstream or wet season. The positive relationship of turbidity level and solids concentrations were suggested in literatures [29-30], however the slope of this relation varied between wet and dry weather conditions, as well as between sites.

The variance of above ten parameters were evaluated the using ANOVA analysis ($\rho < 0.05$). The results revealed that there was no significant difference in spatial variation (i.e. midstream and downstream) and seasonal variation (i.e. wet and dry seasons) for the parameters of temperature, pH, hardness, conductivity and TDS; the average values were 7.7, 156.5 μS/cm, 29.5 °C, 101.9 mg/L and 76.9 mg/L respectively. On the other hand, the turbidity, TS and SS concentrations were significantly higher in the downstream rather than the midstream. There were due to the effluent discharge from human activities and the sediment flushing from upstream which was naturally occurred in accordance to particle size and river topography [31-32]. The significant difference in turbidity and solids concentrations were also observed in seasons. The heavy precipitation during the wet season was a significant cause for soil erosion and increase in suspended solids load to the river [33]. Further, the concentrations of NO_3^- and TP were significant difference in locations (no difference in seasons); the maximal NO_3^- and TP were 1 and 0.5 mg/L in the midstream, whereas the maximal NO_3^- and TP were 1.9 and 0.8 mg/L in the downstream. The high concentrations of NO_3^- and TP was from the effluent domestic discharge which contained chemical cleaning and detergents [34].

3.2 Water quality index (WQI)

The evaluation of surface water quality using WQI via five parameters of DO, BOD, NH_3, TCB and FCB has been implied by Thai government organization, as named PCD. The spatial-seasonal variation of five parameters are shown in Figures 3(i)-3(v) and Table 4. The average DO concentrations were 5.6 and 6.1 mg/L in the midstream and downstream, and they were 5.7 and 5.9 mg/L in the wet and dry seasons. Although there was a slight difference in the average concentration, however a wide DO range was observed in the midstream and dry season. The relative low concentration of 3.6 mg/L was detected one sampling water at ST02 and dry season in 2013. In addition, during 2012-2013, the DO levels were in the range of 3.6-4.5 mg/L which was lower than the range of 5.6-7.0 mg/L in 2014-2016. The average BOD concentrations were 1.7-1.8 mg/L in all locations and seasons. However, the highest BOD of 3.6 mg/L was found in one sampling water at ST04 and wet season in 2012.

For the biological parameters of TCB and FCB, the average concentrations of TCB and FCB were 3,400-4,800 MPN/100mL and 1,100-1,400 MPN/100mL in different locations and seasons. The extreme TCB level of >20,000 MPN/100 mL which is exceeding the standard limit of Class 3 [7] was observed in one sampling water at ST03 and wet season in 2014. On the other hand, the FCB concentration was relatively high in one sampling water at ST01 and dry season in 2012; the values were >4,000 MPN/100ml (limit of Class 3 [7]). The FCB level mainly related to the number of *Escherichia coli* (*E. Coli*) which are facultative bacteria and normally found in intestine of humans and animals [35]. Therefore, a lot of large piggery farms located along the midstream [36] and their waste discharge were possibly reasons for extremely high FCB in this study. For another WQI parameter of NH_3, the mean concentration was around 0.2 mg/L in locations and seasons. Similarly, the maximal values were slightly higher in the midstream and dry season samples. For the above WQI parameters, the significant difference in locations and seasons was not found.

The WQI values were calculated and shown in Figures 4a-4c. From Figure 4a, the average WQI in the wet season was 69.5 at ST01-ST03, and decreased to 67.2 in ST04, which classified to the moderate quality. However, the minimal value of < 60 was observed in ST04 which refers the poor quality. This is because the high BOD of 2.3-3.6 was detected in 2012-2013. The BOD at ST04 achieved the low value of 1.0 mg/L in 2014-2016. From Figure 4b, the average WQI in the dry season was slightly lower than that in the wet season, because the annual precipitation can improve the water quality by pollutants dilution [37], however it can cause the high turbidity and solid contents from soil erosion. The average WQI at ST01-04 was ranged of 67-70, which was the moderate quality. Further, the low WQI of < 60 was found at ST01 and ST02, due to the change of DO and FCB in 2012 (as above discussion). There was no difference in the water quality at various locations in both wet and dry seasons (using ANOVA, $\rho < 0.05$).

Table 1 Sampling points and their coordinates

Sampling points	Latitude	Longitude	Location
ST01	621443 N	1952852 E	Muang District, Uttaradit Province
ST02	616603 N	1947387 E	Muang District, Uttaradit Province
ST03	634341 N	1862169 E	Muang District, Phitsanulok Province
ST04	641149 N	1825285 E	Muang District, Phichit Province

Table 2 Calculation equations of five parameters in WQI [25]

Parameters	Values	Equations
Dissolved oxygen (DO; mg/L)	0.0 – 4.0	Score = 15.25 × (DO value) + 0.1667
	4.1 – 6.0	Score = 5 × (DO value) + 41
	6.1 – 8.4	Score = 12.083 × (DO value) - 1.5
	8.5 – 8.9	Score = -78 × (DO value) + 755.2
	9.0 – 11.2	Score = -13.043 × (DO value) +177.09
	11.3 – (≥15.3)	Score = -7.561 × (DO value) + 115.68
Biochemical oxygen demand (BOD; mg/L)	0.0 – 1.5	Score = -19.333 × (BOD value) + 100
	1.6 – 2.0	Score = -20 × (BOD value) + 101
	2.1 – 4.0	Score = -15 × (BOD value) + 91
	4.1 – (≥8.8)	Score = -6.4583 × (BOD value) + 56.833
Ammonia (NH_3; mg/L)	0.0 – 0.22	Score = -131.82 × (NH_3 value) +100
	0.23 – 0.50	Score = -35.714 × (NH_3 value) + 78.857
	0.51 – 1.83	Score = -22.556 × (NH_3 value) + 72.278
	>1.83	Score= -6.1024 × (NH_3 value) + 42.167
Total coliform bacteria (TCB; MPN/100mL)	0.0 – 5,000	Score = -0.0058 × (TCB value) + 100
	5,001 – 20,000	Score = -0.0007 × (TCB value) + 74.333
	20,001–160,000	Score = -0.0002 × (TCB value) + 65.286
	>160,000	Score = -8E-06 × (TCB value) + 32.292
Feacal coliform bacteria (FCB; MPN/100mL)	0.0 – 1,000	Score = -0.029 × (FCB value) + 100
	1,001 – 4,000	Score = -0.0033 × (FCB value) +74.333
	4,001 – 90,000	Score = -0.0003 × (FCB value) +62.395
	>90,000	Score = -1E-05 × (FCB value) + 32.208

Table 3 Water quality criteria in accordance with WQI

Surface water quality standards	Score	Water quality criteria
Class 1	> 100	Excellent
Class 2	71 - 100	Good
Class 3	61 - 70	Moderate
Class 4	31 - 60	Poor
Class 5	< 30	Very poor

Table 4 Summary of the physico-chemical and microbiological characteristics of Nan river during a 5-year period (2012-2016).

Sampling point	Temperature	pH	Hardness	Conductivity	TDS	Turbidity	TS	SS	NO_3^-	TP	DO	BOD	TCB	FCB	NH_3
ST01-Wet	30 ± 2.3	7.6 ± 0.7	87 ± 17	163 ± 12	106 ± 21	27 ± 27	143 ± 30	33 ± 25	0.3 ± 0.3	0.2 ± 0.1	5.6 ± 1.0	1.7 ± 0.6	3733 ± 4968	1495 ± 2038	0.2 ± 0.1
ST01-Dry	29 ± 2.0	7.8 ± 0.2	79 ± 7.0	156 ± 5.8	98 ± 20	41 ± 44	141 ± 36	27 ± 26	0.2 ± 0.2	0.2 ± 0.1	5.7 ± 1.0	1.7 ± 0.6	4289 ± 4818	2444 ± 4997	0.2 ± 0.1
ST02-Wet	30 ± 2.3	7.5 ± 0.7	82 ± 11	166 ± 14	95 ± 27	52 ± 57	162 ± 76	52 ± 64	0.3 ± 0.3	0.2 ± 0.2	5.5 ± 0.9	1.6 ± 0.4	4269 ± 4793	884 ± 942	0.2 ± 0.1
ST02-Dry	28 ± 1.8	7.8 ± 1.8	80 ± 5.8	157 ± 10	96 ± 28	44 ± 48	143 ± 39	33 ± 26	0.2 ± 0.2	0.3 ± 0.1	5.5 ± 1.0	1.7 ± 0.7	2912 ± 3384	1253 ± 2744	0.2 ± 0.1
ST03-Wet	29 ± 1.3	7.7 ± 0.2	72 ± 5.9	156 ± 12	114 ± 26	98 ± 68	184 ± 42	59 ± 32	0.4 ± 0.3	0.4 ± 0.3	6.1 ± 0.5	1.5 ± 0.4	6499 ± 7758	1056 ± 1119	0.2 ± 0.1
ST03-Dry	30 ± 2.3	7.8 ± 0.1	75 ± 12	157 ± 16	103 ± 26	52 ± 22	159 ± 33	38 ± 25	0.3 ± 0.1	0.3 ± 0.2	6.2 ± 0.9	1.8 ± 0.5	1744 ± 1108	656 ± 1058	0.1 ± 0.1
ST04-Wet	31 ± 2.0	7.7 ± 0.3	70 ± 8.1	148 ± 15	95 ± 34	105 ± 88	212 ± 42	39 ± 25	0.4 ± 0.3	0.4 ± 0.2	5.8 ± 0.6	1.9 ± 0.8	4524 ± 4809	1136 ± 773	0.1 ± 0.1
ST04-Dry	30 ± 2.2	7.8 ± 0.2	74 ± 12	152 ± 13	110 ± 27	51 ± 30	166 ± 37	40 ± 25	0.5 ± 0.5	0.4 ± 0.2	0.2 ± 0.7	1.9 ± 0.5	8840 ± 6574	1989 ± 2504	0.2 ± 0.1

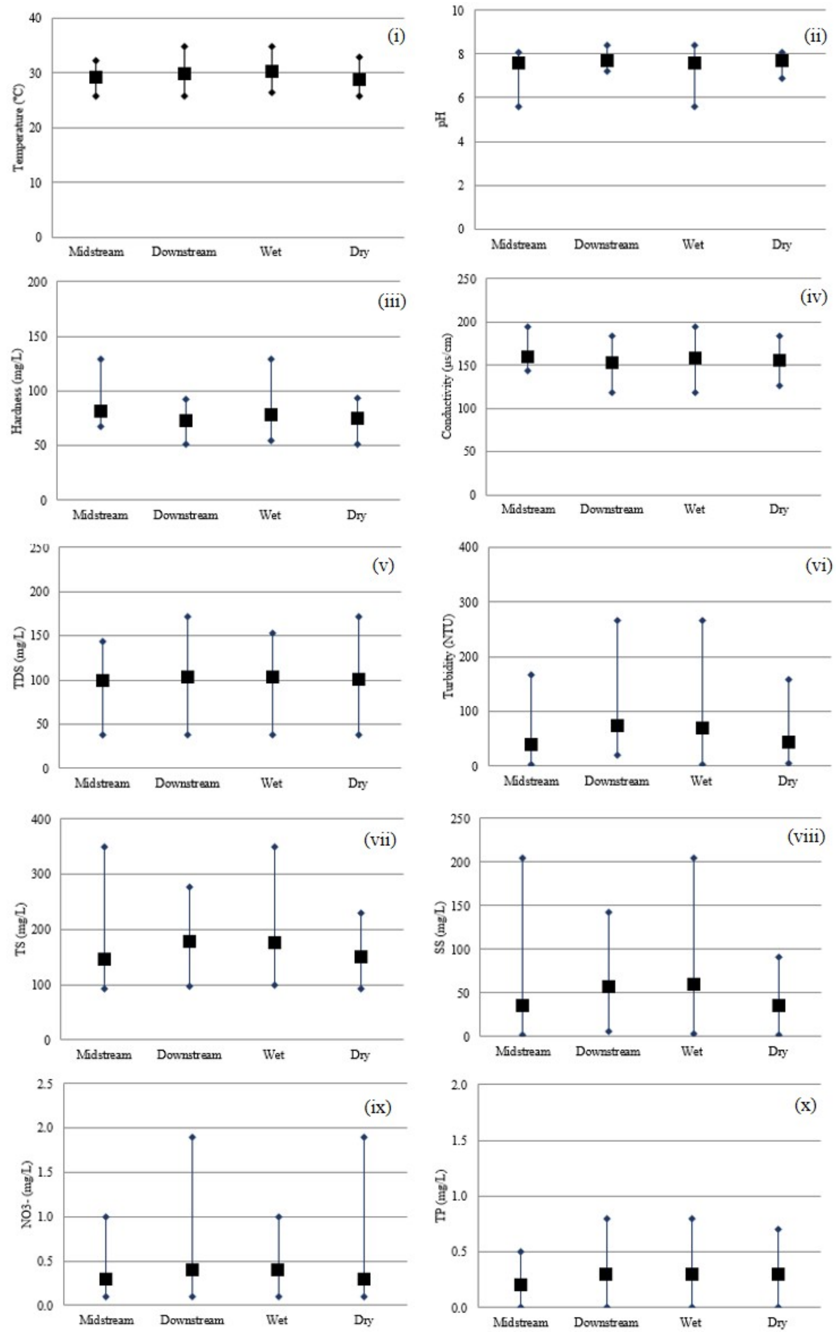

Figure 2 Spatio-seasonal dynamics of parameters; (i) temperature, (ii) pH, (iii) hardness, (iv) conductivity, (v) total dissolved solids, (vi) turbidity, (vii) total solids, (viii) suspended solids, (ix) nitrate and (x) total phosphorus

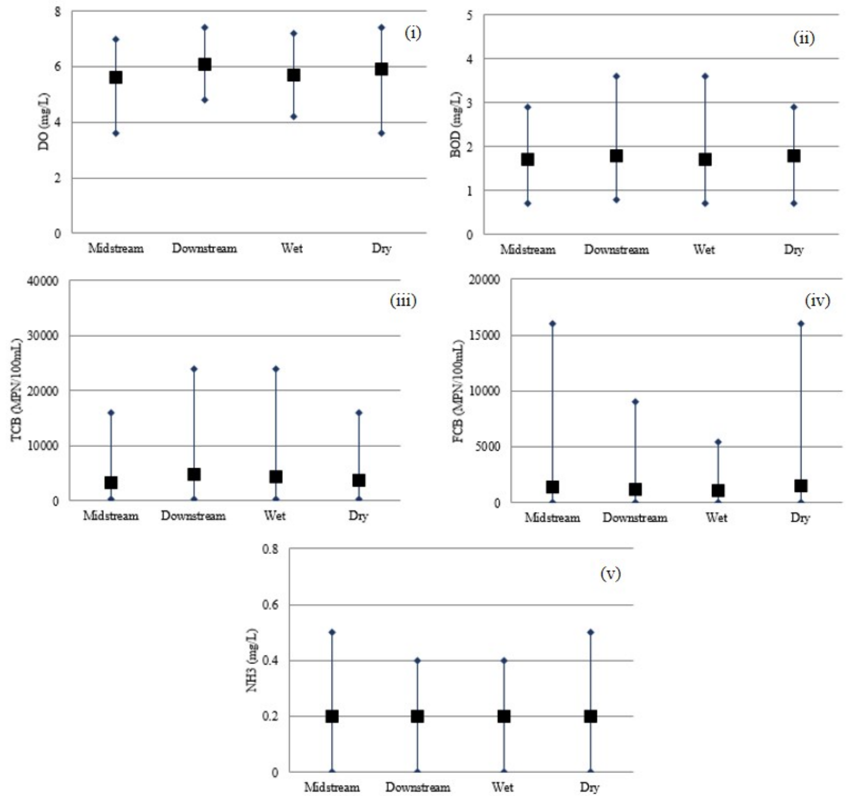

Figure 3 Spatio-seasonal dynamics of parameters; (i) dissolved oxygen, (ii) biological oxygen demand, (iii) total coliform bacteria, (iv) faecal coliform bacteria and (v) ammonia

The WQI values were also presented in temporal variation (Figure 4c). The average WQI was ranged of 60-70 in 2012-2014, refers to the moderate quality of Nan river. However, the minimal WQI was defined in the poor quality. The average WQI reached to 71 in 2015 and 72 in 2016 which classified in the good quality, however the poor quality of Nan river was also detected in 2016. According to this study, the key parameters effected on decreasing water quality of Nan river were DO, BOD and FCB.

All above results suggested that the increasing population and fertilizer uses during 2012-2016 had no significant impacts on decreasing the water quality of Nan river. The important reason was that the self-purification (i.e., by microorganisms and dilution) was still effective. However, the local residents should maintain and improve the quality of Nan river to be an excellent water resource. Various activities should be done for conserving the river, such as reforestation, soil erosion prevention, reduction of fertilizer uses, no waste and wastewater discharges, and regular water quality monitoring. These activities will benefit the human, water resource and environment.

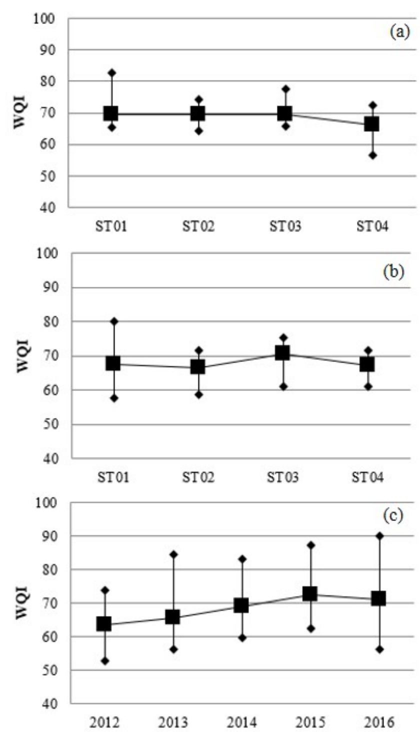

Figure 4 Water quality index (WQI) in Nan river; (a) spatial variation in wet season, (b) spatial variation in dry season, and (c) temporal variation

4. CONCLUSIONS

During increasing the population and agricultural activities along Nan river from 2012 to 2016 [1, 4], the Nan river was still not polluted; the mean quality was moderate with spatial WQI score of 68.7 in the wet season and 67.9 in the dry season. For the spatial variation, the water quality had no significant difference. However, there was significant different in parameters of turbidity, TS, SS, NO_3^- and TP ($\rho < 0.05$); the greater levels were observed in the downstream rather than the midstream. The concentrations of turbidity, TS and SS were higher in the wet season rather than that in the dry season significantly. All the results revealed the self-purification of Nan river has been efficient. However, the increasing people awareness for pollution prevention is important for preserving sustainable water resource.

5. REFFERENCE

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